A New Evaluation Methodology For Measuring Highway Safety Using a Microscopic Traffic Simulator

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Ⅰ. Introduction

Highways are designed to maintain the speeds that satisfy most of the drivers using the facility. Consideration in design should be given to the type and characteristics of the drivers expected to use the highway. For safety on highways the designer applies the minimum design criteria that drivers can control the operations of their vehicles to avoid accident.

The safety of vehicles on highways is, however, subject to the driver's ability, training, and experience. It means that the safety of the highway could be different depending on the driver's behavior. This paper addresses the methodology of evaluating highway safety in the viewpoint of driver's behavior and suggests the maximum speed limit on the highway.

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II. State-of-the-Art

In general, the safety of roadways is evaluated by criteria based on achieving driving consistency. Lamm suggests three types of safety criteria which are closely related to the curvature change rates of the single curve: achieving design consistency, achieving operating speed consistency, and achieving driving dynamic consistency. Table 1 summarized the recommended ranges for design levels for three types of safety criteria.

Table 1. Recommended Ranges for Good, Fair, and Poor Design Levels for Safety Criteria Design Levels

Design Levels Criteria	Good	Fair	Poor
CCR_S	$\leq 180 gon/km$	$> 180 gon/km, \leq 360 gon/km$	$> 360 gon/km$
Criteria I	$\lvert V85_I - V_d \rvert \leq 10 km/h$	$10 km/h < \lvert V85_I - V_d \rvert \leq 20 km/h$	$\lvert V85_I - V_d \rvert > 20 km/h$
Criteria II	$\lvert V85_I - V85_{I+1} \rvert \leq 10 km/h$	$10 km/h < \lvert V85_I - V85_{I+1} \rvert \leq 20 km/h$	$\lvert V85_I - V85_{I+1} \rvert > 20 km/h$
Criteria III	$f_{RA} - f_{RD} \geq +0.01$	$-0.04 \leq f_{RA} - f_{RD} < +0.01$	$f_{RA} - f_{RD} < -0.04$

(source: ref. 1, p. 11.3, table 11.1)

note: Criteria I: achieving design consistency
Criteria II: achieving operating speed consistency
Criteria III: achieving driving dynamic consistency

Where,

CCR_s	:	Single Curve Lane Curve Change Ratio (gon/km)
Vd	:	Design Velocity (km/h)
$V85_I$	:	85th Percentile desired speed on Curve I (km/h)
$V85_{I+1}$	:	85th Percentile desired speed on Curve I+1 (km/h)
f_{RA}	:	Deduction Horizontal Coefficient of Friction = n0.925f_T
f_{RD}	:	Required Horizontal Coefficient of Friction = V852/127R-e
f_T	:	Horizontal Coefficient of Friction

III. Methodology

The primary measurements of safety are the possibilities of rear-end accident, high speed, abrupt change of acceleration and deceleration speed of individual vehicles on his driving. The safety of vehicles on highways is evaluated as following safety indices.

1. Rear-end Accident Index

Rear-end accident can be avoided when the vehicle on the highway maintain the sufficient distance from the preceding vehicle (i.e. y > d). No collision will occur in event of sudden stop when the desired spacing between vehicles is provided in the micro simulation.

$$d = 0.278u_{n+1} \times B_t + \frac{u_{n+1}^2}{254(F \pm G)} \qquad (1)$$

Where,

a	:	minimum stopping distance (m)
u_{n+1}	:	the speed of following vehicle (km/h)
F	:	friction factor
G	:	grades
B_t	:	reaction time (2.5sec)

$$y = x_n - x_{n+1} - L_n + \frac{u_{n+1}^2}{254(F \pm G)} \qquad (2)$$

Where,

Y	:	space headway (m)
x_n	:	position of preceeding vehicle (m)
x_{n+1}	:	position of following vehicle (m)
L_n	:	length of preceeding vehicle(m)

2. Speed Index

On the curve section of the roadway, sliding or overturn can be prevented when the vehicle travels slower than the balance speed from the laws of mechanics (i.e $V > \sqrt{127(e+f)R}$)

Table 2. Ranges of Acceleration Rates for Design Levels

Deceleration speed (m/s^2)	status	acceleration speed (m/s^2)
1.00 - 1.48	safe (good)	0.54~0.89
1.48 - 2.00	safe (fair)	0.89~1.25
> 2.00	dangerous	> 1.25

(source: ref. 1)

$$V = \sqrt{127(e+f)R} \tag{3}$$

Where,

V : design speed (km/h)

R : minimum radius of curve (m)

E : maximum permissible side friction factor

f : maximum superelevation rate (%/100)

3. Acceleration Index

The vehicle is exposed to danger when the acceleration speed of vehicle is higher than the 1.25 m/s^2, or the deceleration speed is lower than the 2.0 m/s^2.

IV. Design of Experiment

1. Test Network

The safety of individual vehicles on highways was evaluated on the test network. The test network consists of 600m length of freeway section with 630m of curve radius. The algorithm was employed on the microscopic simulator which was developed by the research Team of the University of Seoul. Figure 1 and Table 3 represent the configuration of the test network.

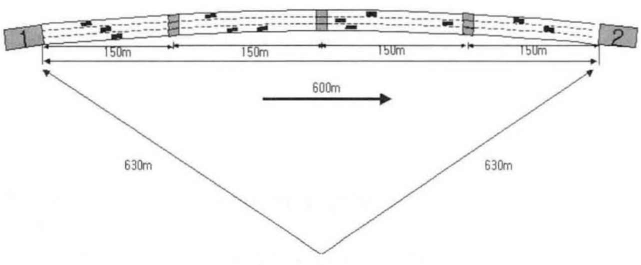

Figure 1. Test network

Table 3. Test Network Configuration

A Number of Lane	Length	radius of curve	super-elevation	design speed	grades
3	600m	630m	8%	120km/h	0
Detector	Three detectors on each lane Detector locations: 150m, 300, 450m from entering point Data collection: The data of position, speed, acceleration rate, and headway for individual vehicle were collected on every 0.1 second interval by XIM.				
Simulation time	30 min.				
v/c ratio	0.34				
average entering speed	95 km/h				

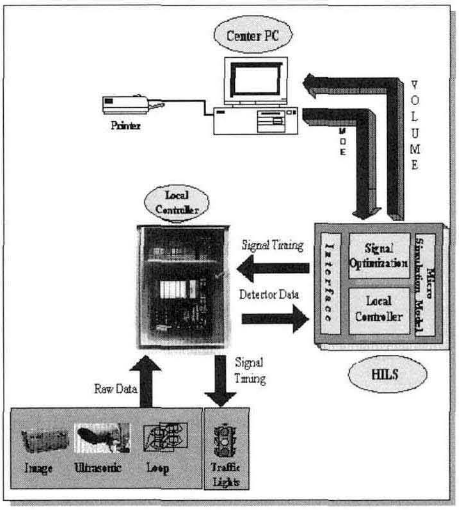

Figure 2. Architecture of HILS (Microscopic Simulator)

2. Microscopic Simulation Model

The safety of vehicles on the test network are simulated using HILS(Hardware-in-the Loop Simulation), which was developed by the research Team of the University of Seoul (b). The micro-simulator, HILS, consists of four modules: detector emulation module, internal controller emulation module, micro-simulation module, and animation module.

The architecture of HILS, which was applied to evaluate the safety of individual vehicle on the test network are shown as Figure 2.

V. Results

1. Traffic Flow Characteristics

1) Speed Distributions

Figure 3 shows the speed distribution of individual vehicles passing through the 0m, 150m, 300m, 450m of the test network, respectively. The vehicles driving faster than 120km/h have the potential of over turning on the test network. The speed characteristics at each point were summarized in table 4. The standard deviations of spot speeds at the 0m, 150m, 300m, and 450m were estimated as 12.4km/h, 9.3km/h, 8.2km/h, and 8.3km/h, respectively.

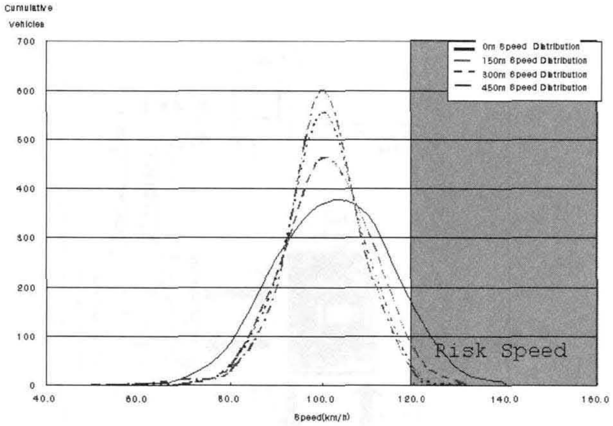

Figure 3. Speed Distribution at Detector Locations

Table 4. Speed Characteristics at Detector Locations

detector location		0m	150m	300m	450m
Speed	maximum	135.3	130.0	127.1	127.0
	minimum	54.5	48.3	60	56.8
	mean	97.3	96.5	95.4	95.1
	standard deviation	12.4	9.3	8.2	8.3

2) Acceleration

Figure 4 shows the acceleration distribution of individual vehicles passing through the 0m, 150m, 300m, 450m of the test network, respectively. The vehicles which have lager than 1.25m/sec2 of acceleration rate and lager than 2m/sec^2 of deceleration rate can be exposed to the rear-end accident on the test network. The speed characteristics at each point were summarized in Table 5. The maximum acceleration rates at the 0m, 150m, 300m, 450m were estimated as 2.63m/sec^2, 1.52m/sec^2, 1.25m/sec^2, 1.25m/sec^2, and the maximum deceleration rates were analyzed to -4.34m/sec^2, -1.79m/sec^2, -3.83m/sec^2, -2.29m/sec^2, respectively.

3) Headway Distribution

Figure 4 shows the headway distribution of individual vehicles passing through the 0m, 150m, 300m, 450m of the test network, respectively. The vehicles which have lager than 9.0 second of headway were assumed to be the preceding vehicles of the platoon. The headway characteristics at each point were summarized in Table 5.

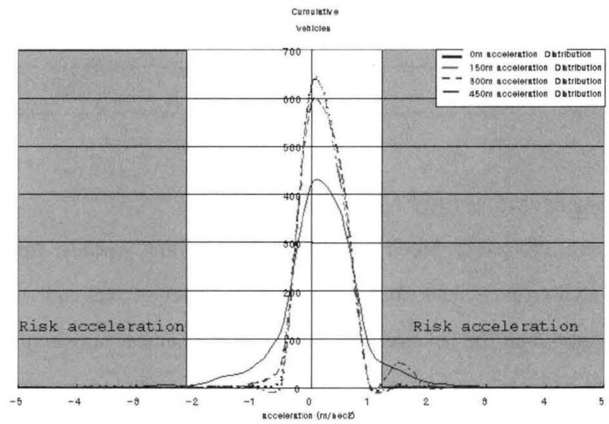

Figure 4. Acceleration Distribution at Detector Locations

Table 5. Acceleration Characteristics at Detector Locations (m/sec^2)

detector location	0m	150m	300m	450m
mean	-0.13	-0.06	-0.04	0.05
standard deviation	0.72	0.26	0.28	0.31
max. acceleration	2.63	1.52	1.25	1.25
max. deceleration	-4.34	-1.79	-3.83	-2.29

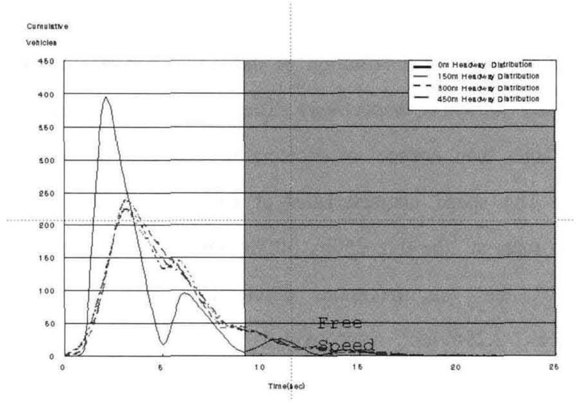

Figure 5. Headway Distribution at Detector Locations

Table 6. Headway Characteristics at Detector Locations (sec)

detector location	0m(sec)	150m(sec)	300m(sec)	450m(sec)
mean	3.7	4.8	4.8	4.8
standard deviation	3.0	2.8	2.9	2.9
max. headway	21.1	22.4	22.6	22.5
max. headway	0.8	0.5	0.4	0.4

2. Safety Analysis using Micro-Simulator

Test Results were compared based on the different limit speeds from 80km/h to 120km/h, respectively. The MOEs for vehicle safety are (1) the number of real-end accident possibility, (2) the number of speed faster than the balance speed, and (3) the number acceleration indices in danger. The numbers of indices will be counted on 0.1 second interval using microscopic simulator.

1) Rear-end Accident Index

Table 7 and figure 6 show the rear-end accident potential rates at 0m, 150m, 300m, and 450m of detector locations. In terms of rear-end accident potential rates; the following vehicles whose travel speeds are under 90 km/h are comparatively safer than high speed vehicles at detector locations. Figure 6 represents that the rear-end potential rates are rapidly increased when the travel speeds are over than 90 km/h. The result suggests that the speed limit of the test network is recommended to 90 km/h to lessen the rear-end accident potentials.

Table 7. Rear-end Accident Potential Rate

Detector location	pase (km/h)	detected volume	number of real-end accident possibility	rear-end accident possible rate (%)
0m	80~90	370	185	50.0
	90~100	345	259	75.1
	100~110	157	144	91.7
	110~120	33	32	97.0
	120~130	6	6	100.0
150m	80~90	230	44	19.1
	90~100	426	188	44.1
	100~110	317	200	63.1
	110~120	89	63	70.8
	120~130	5	4	80.8
300m	80~90	242	53	21.9
	90~100	531	266	50.1
	100~110	270	185	68.5
	110~120	37	32	86.5
	120~130	1	1	100
450m	80~90	273	67	24.5
	90~100	538	261	48.5
	100~110	250	179	71.6
	110~120	35	28	80.0

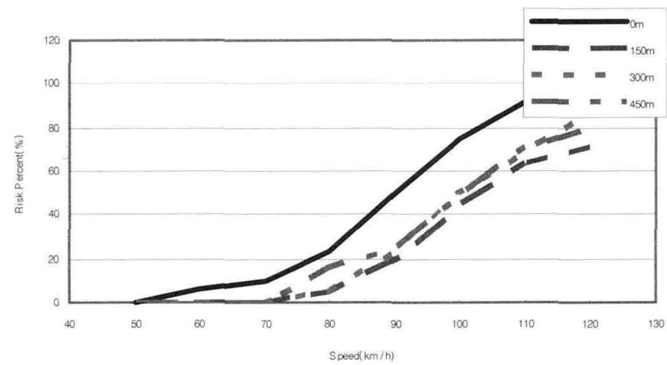

Figure 6. Rear-end Accident Potentials at Detector Locations

2) Speed Index

Overturn accidents are caused by high speeds. Table 8 and Figure 7 show the overturn accident potential rates at 0m, 150m, 300m, and 450m of detector locations. Most of the high speed vehicles whose travel speeds are over 120km/h are in danger of overturn accident. These results are shown as Figure 7. The result suggests that the speed limit of the test network is setup to minimize the number of high speed vehicles to lessen the overturn accident potentials.

3) Acceleration Index

Table 9 and Figure 8 show the accident potential rates caused by abrupt acceleration or deceleration

Table 8. Overturn accident Potential Rate

Detector location	pase (km/h)	Detected volume	number of overturn accident possibility	over-turn accident possible rate (%)
0m	110~120	33	33	100
	120~130	6	6	100
150m	110~120	89	0	0
	120~130	5	5	100
300m	110~120	37	0	0
	120~130	1	1	100
450m	110~120	35	0	0
	120~130	0	0	0

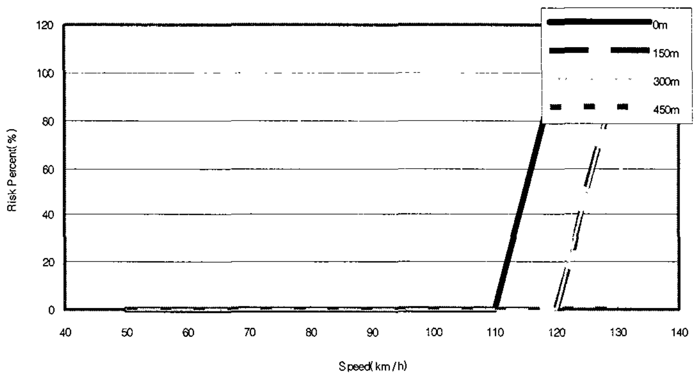

Figure 7. Overturn Accident Potentials at Detector Locations

at 0m, 150m, 300m, and 450m of detector locations. In terms of acceleration accident potential rates, the following vehicles whose travel speeds are between 90km/h to 100km/h are comparatively safer than other speed ranges. The results are shown in figure 8. The result suggests that the speed limit of the test network is setup in the range of 90km/h to 100km/h to lessen the acceleration accident potentials.

Table 9. Acceleration Accident Potential Rate

Detector location	pase (km/h)	detected volume	number of acceleration accident possibility	acceleration accident possible rate (%)
0m	80~90	370	8	2.2
	90~100	345	6	1.7
	100~110	157	20	12.7
	110~120	33	5	15.2
	120~130	6	1	16.7
150m	80~90	230	3	1.3
	90~100	426	1	0.2
	100~110	317	3	0.9
	110~120	89	3	3.4
	120~130	5	1	20
300m	70~80	42	3	7.1
	80~90	242	2	0.8
450m	70~80	26	3	11.5
	80~90	273	4	1.5
	90~100	538	0	0
	100~110	250	0	0
	110~120	35	1	2.9

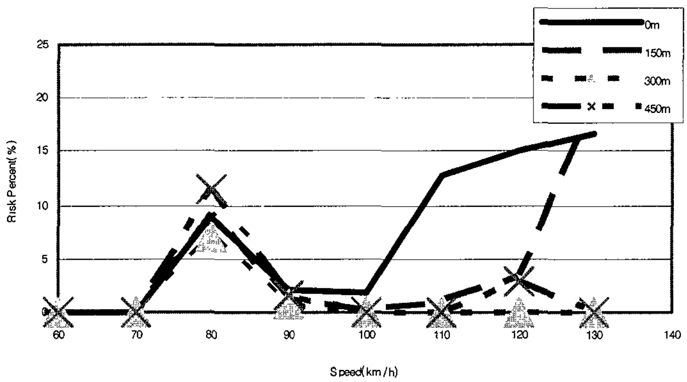

Figure 8. Acceleration Accident Potentials at Detector Locations

VI. Findings

In summary, the possible number of vehicles exposed to the rear-end accident, overturn accident, and acceleration accident are simulated as 602, 40, and 65 vehicles, respectively. Table 10 summarizes the accident potential rates.

In the overturn accident potential analysis, most of vehicles whose travel speeds are higher than 110km/h are exposed to the danger of accident. In terms of acceleration index, the vehicles traveling in the speed range of 90km/h to 100km/h are safer than the vehicles of other speed ranges. The vehicles traveling under 90km/h are comparatively in low potentials of rear-end accident. Table 11 and Figure 10 summarizes the simulation results of accident potentials on the test network. In conclusion, the speed limit of 90km/h is recommended for the test network.

Table 10. Summary of the accident potentials

average speed (km/h)	detected volume (veh)	Number of rear-end accident potentials (veh)	Number of acceleration accident potentials(veh)	number of overturn accident potentials(veh)
96	1,108	602	65	40

Table 11. Summary of accident potential rates (%)

speed(km/h) potential rates(%)	80	90	100	110	120
rear-end accident	12	29	54	74	84
acceleration accident	9	1	0	3	5
overturn accident	10	0	0	0	25

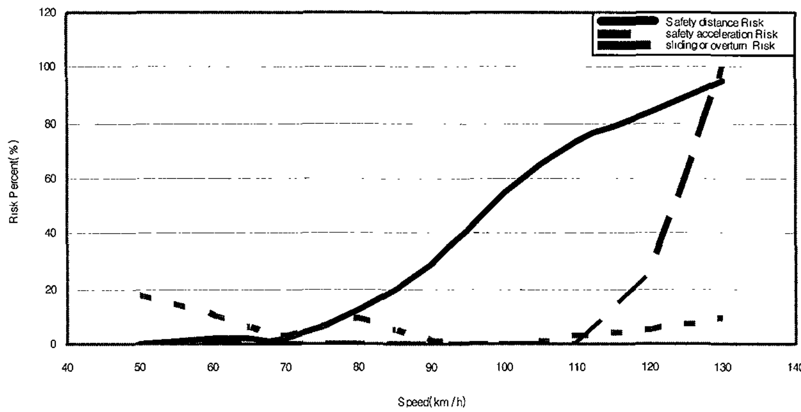

Figure 10. Summary of accident potential rates

References

Kay Fitzpatrick et al. "Evbaluation of Design Consistency Methods for two-Lane Rural Highways Executive Summary", FHWA-RD-99-173, FHWA, 2000.

Nicholase J. Garber & Ravi Gadiraju, "Factors Affecting Speed Variance and Its Influence on Accidents", TRR 1212, TRB, 1989.

Ruediger Lamn, Basil Parianos & Mailaender, "Highway Design and Traffic Safety Engineering Handbook", McGraw-Hill, 1999.

L. A. Pipes, Hydrodynamic Approaches-part I; An Introduction to Traffic, Oper Res, 9(1), 1961.

J. W. Mc Clenahan and H. J. Simkowitz, The Effect of Short Cars on Flow and Speed in Downtown Traffic: A Simulation Model and Some Results. Transport Sci 3(2), 1969.

P.Fox and F. G. Lehman, Safety in Car Following-A Compuper Simulation, Newark Coleage of Engineering, 1967.

W. R. Mc Shane, R. P. Roess, E. S. Prassas, TRAFFIC ENGINERING Second Edition.